OHIO STATE UNIVERSITY WORKING PAPERS IN LINGUISTICS 38 (1-23)

Asymmetries in Naming Accuracy and in Event-related Potentials for Laterally Presented Words of Variable Morphological Complexity

Brian McAdams

University of Minnesota

Abstract: Recent studies indicate that hemispheric asymmetries in lexical access exist, with the left hemisphere being superior in processing morphologically complex words. The present study looks for asymmetries in naming accuracy and in topographically displayed event-related potentials to laterally presented words. Data were collected from six subjects while words were presented to both visual fields. Right visual field superiority in naming accuracy was demonstrated for suffixed forms as expected, indicating a potential left hemisphere advantage for morphological processing. Event-related potential data revealed stimulus-relevant positive parietal peaks around 320 msec.

1. Introduction

Evidence has been accumulating for the past 150 years that the cognitive processing of language is asymmetrically localized within the cerebral cortex. The earliest evidence came exclusively from studies of individuals with language deficits resulting from stroke or trauma. Such aphasic individuals display a wide variety of disturbances of language comprehension, language production, or both; and, in nearly every case, this deficit results from a perisylvian lesion in the left cerebral cortex. Individuals with similar lesions in the right hemisphere usually did not display language deficits, or, if they did, their deficits in linguistic functioning differed from those resulting from left-hemisphere damage. For example, lesions to the ventrolateral frontal cortex and the dorsolateral temporal cortex (both near the sylvian fissure) generally only result in language impairment with a left hemisphere locus (Hecaen and Albert 1978).

More recently, other sources of evidence for the lateralization of linguistic processing have been utilized. For example, studies of hemispherectomy patients have shown that the removal of the left hemisphere can result in a variable amount of language loss; in some cases (e.g. if the left hemisphere is removed relatively early in life), the right hemisphere can perform phonological and semantic processing, but it tends to have considerable difficulty with syntactic processing (Millar and Whitaker 1983; Todorovic 1988).

Investigations of split-brain patients who have undergone partial or complete callosectomies have revealed that the right hemisphere does have a limited linguistic

competence, but it is apparently unable to process many (if not most) function morphemes and it is unable to make many important syntactic distinctions, such as active/passive, past/future, singular/plural (Zaidel 1978; Todorovic 1988). Millar and Whitaker (1983) warn that we should be cautious in looking at evidence from split-brain subjects because their brains are not normal- due to the damage that caused the epilepsy (which the surgery was designed to treat), as well as because of the damage caused by the operation (i.e. one side of the brain must be pulled back to reach the corpus callosum, some arteries must be clamped (thus starving some tissues), and retrograde axonal degeneration may cause further damage). Also, neural plasticity may have allowed some cognitive functions to shift to the unimpaired hemisphere from the hemisphere with the epileptic locus in pre-operative split-brain patients, thus making the functional capacities of the post-operative commissurotomy patient studied by the researcher atypical. A direct comparison between the normal subject and the split-brain patient may therefore be inappropriate or at least regarded with caution (Millar and Whitaker 1983).

Lateralization of language processing has also been observed using the Wada test which reveals the hemisphere that is dominant for language functions in the pre-operative brain surgery patient. In this test, the patient receives an injection of sodium amytal in the inner carotid artery at the point where the blood flow is unilateral. Of over 36 patients tested by Millar and Whitaker (1983), one had bilateral language representation, one was unilaterally right hemisphere dominant for language, and the rest were unilaterally left hemisphere dominant for language processing (using a naming task).

Changes in metabolic activity have been measured using PET-scan technology to localize centers of language processing throughout the brain. Millar and Whitaker (1983) state that verbal analogy testing has been shown to result in elevated metabolic activation of Wernicke's area in the temporal lobe. Petersen et al. (1988) investigated the relationship between auditory and visual lexical processing using a PET-scan subtraction technique with promising results. They found different cortical areas (in both hemispheres, but primarily in the left hemisphere) support visual and auditory word processing (primary and "non-primary").

Brain stimulation studies utilizing electrode stimulation of cortical tissue of conscious brain surgery patients such as those of Ojemann and Whitaker (Millar and Whitaker 1983) have shown "that language lateralization can be quite complete," the right hemisphere contributing little to language processing at least as it is measured by their technique.

Non-invasive techniques have also been used to study the lateralization of language processing, the most popular being: dichotic listening, divided visual field stimulation, and event-related potential studies. The first of these utilizes a binaural presentation of linguistic stimuli. This dichotic listening task assumes that an individual with left hemisphere language dominance will have a right ear advantage in accuracy of reporting different words presented simultaneously to both ears. This

occurs as a result of the majority of ascending auditory axons synapsing in the contralateral auditory cortex of the temporal lobe (Borden and Harris 1984). However, there are a number of commissures in the ascending auditory pathways, and in addition to these subcortical decussations, there is the large cortico-cortical commissure, the corpus callosum mentioned above, which can allow the temporal lobe auditory centers to transfer information (Durrant and Lovrinic 1984). Indeed, for language studies, these commissures may have a detrimental effect on the usefulness of dichotic listening tasks for the study of cerebral lateralization of language. For example, Todorovic (1988) points out that, in general, morphosyntactic studies using a dichotic listening task have failed to give consistent results. These same difficulties have been encountered by other experimenters with different stimuli using this task.

Perhaps the most widely used technique for studying language lateralization has been the divided visual field technique in which linguistic stimuli are briefly presented laterally to the left or right visual hemifield, or both, using a tachistoscope or video display terminal. Unlike the organization of the auditory afferents, the visual afferents remain isolated so that both visual fields do not receive extensive bilateral representation in the cortex. Instead, the temporal visual field, that part of the visual field that falls on the half retina furthest from the nose (the temporal hemiretina) in each eye, projects ipsilaterally through the optic nerve to the occipital cortex. By contrast, that part of the visual field that falls on the half retina closest to the nose in each eye (the nasal hemiretina) projects contralaterally to the occipital cortex. Thus, all optical stimuli appearing to the left of the point of focus are initially processed by the right hemisphere while the left hemisphere initially processes stimuli in the right visual field (Anderson, 1982).

Although the divided visual field technique does have the advantage of a relatively more isolated ascending neural pathway than does the auditory system, it does pose some technical difficulties for the lateralization experimenter. Young (1982) discusses these potential limitations at some length and their resolutions as proposed by various researchers. For example, it is not uncommon for investigators to present words outside of the central or foveal region of the visual field which has been shown to have some bilateral representation in the striate cortex of the occipital lobe (Young 1982; Beaumont 1982; Leventhal et al. 1988; Beaton 1985; McKeever 1986), although the precise size of the bilaterally projecting area and the perceptual significance of this bilateral representation are not well understood. McKeever (1986) points out that the overlap may be ignored at higher levels of the visual system, and Young (1982) and Leventhal et al. (1988) suggest that the overlap may be involved in stereopsis. Beaton (1985) supports the latter point with evidence from split-brain patients that have difficulty with depth perception of the stimuli placed in front of or behind the point of fixation. In hopes of avoiding any possible bilateral initial processing of the experimental stimuli, experimenters present stimuli to the parafoveal region of the visual field.

Presentation of stimuli to the areas surrounding the fovea, the part of the visual field with the highest visual acuity, results in another point of contention: can

the loss of acuity in the parafovea and the resulting stimulus degradation lead to misleading results in laterality studies? Chiarello (1988) compellingly argues against the controversial claim of Schwartz and Kirsner (1986) that visual acuity gradients account for the commonly observed right visual field (RVF) advantage for laterally presented words. They claim that the initial syllable is crucial for lexical access, and that it is more difficult to obtain in a left visual field (LVF) presentation. Chiarello has found that this theory of lexical access has little support and that other parts of monomorphemic words can be just as important as the syllable in accessing the word; indeed, that the whole word is what must be used for access. In an earlier study, Chiarello et al. (1986) found that varying duration, retinal eccentricity, and size of the stimuli to determine the potential contributions of these factors to asymmetries in lexical decision tasks with lateralized stimulus presentation did not affect the RVF advantage; suggesting that both hemispheres can use degraded sensory information relatively equally.

Stimulus duration is also a potentially crucial factor in divided visual field studies because of the potential that saccadic eye movements could bring the stimulus into the center of the visual field resulting in bilateral processing. This is especially important because it is hard to resist fixating on new stimuli. For this reason the stimulus must be presented for an interval shorter than that required to move the eyes such that the word is brought into the fovea. Stimulus location, intensity, size, and other factors can influence the latency and duration of a saccadic eye movement, but on average the saccade will begin about 180-200 msec post-stimulus onset in laterality studies and the saccade itself lasts about 20-30 msec (Young 1982). Young (1982) points out that for about 40-50 msec before and after, as well as during, a saccade, there is a significant loss of visual acuity. The range of stimulus durations used is highly variable, but the 50-200 msec range is most commonly used (Young 1982; Beaumont 1982). It might be noted that 100 msec are needed to "disengage . . . attention from any location in the visual field" and that saccade latency has been shown by Braun and Breitmeyer (1988) to depend on this variable rather than on the end of the fixation, and that attention can shift within the visual field without voluntary eye movement.

The divided visual field technique is frequently used with a lexical decision task (i.e. the subject is to say whether the stimulus is a word or not) or a naming task (i.e. the subject is to name the word they may have seen), and the accuracy and/or reaction time of the response is recorded. Both of these tasks and their measures are not looking at language processing as it occurs, but some time afterwards, potentially after other kinds of processing, even possibly interhemispheric transfer, could have occurred. The indirectness of the divided visual field technique can be corrected to some degree by coupling it with recordings of the brain wave activity during and after stimulus presentations. These event-related potentials (ERPs) "are changes in the electrical activity of the nervous system that are temporally associated with physical stimuli or psychological processes" (Picton and Stuss 1984). This method has the advantage of allowing the observer to indirectly "observe" the linguistic phenomenon of interest by measuring changes in the latency, amplitude, and/or spatial distribution of changes in the brain's electrical field that

occur during and after stimulus processing rather than simply measuring behaviors long after processing has begun (and possibly been completed). The value of this approach for studies of the lateralization of different types of linguistic processing then is apparent, if differences in these variables can be correlated with differences in linguistic stimuli. For example, evidence for the lateralization of morphosyntactic processing to the left hemisphere might be proposed if a significantly larger potential could be localized to that hemisphere in conjunction with the processing of plural nouns but not with uninflected nouns.

ERPs recorded from scalp electrodes are not free of problems, however, in that many possible "sources with temporally and spatially overlapping fields" can generate them; thus, "each peak recorded in the scalp ERP does not necessarily reflect a separate cerebral process" (Picton and Stuss 1984). Considerable caution must therefore be taken in the interpretation of ERP data. Regan (1989) points out that "the more successful efforts at localizing intracranial (ERP) sources have involved large numbers of recording sites." A reliable method has also been developed to aid in ERP source derivation by Hjorth (1980). Thus, the problems arising from wave superposition, increase in amplitude of peaks of identical polarity or cancellation of peaks of opposite polarity (Allison et al. 1981; Regan 1989), can to a limited degree be overcome provided the generators of the summating potentials are at least as far apart as the electrodes. Studies such as those of Ducati et al. (1988) which demonstrated, using intracerebral recording as well as scalp electrodes in alert humans, that the VEP neural generators are completely within the striate cortex.

Previous studies of language processing using ERP techniques have primarily looked at phonetic segments, syllables, content/function words, and some sentence contexts (Picton and Stuss 1984; Molfese 1983; Garnsey 1985; Samar and Berent 1986; Kutas et al. 1988) with widely varied results. In part, this variability results from the lack of uniformity in divided visual field techniques, task selection, electrode montages, linguistic stimuli, and other variables as well (Molfese 1983). An example is seen in the work of Brown et al. (1976 (discussed in Picton and Stuss 1984)) who recorded ERPs to words in a common frame, "It was . . .", where the target word could be either a noun or a verb. Analyses found significant differences between nouns and verbs on the left anterior scalp. Principle components analysis of the same data (Brown et al. 1979, discussed in Picton and Stuss 1984) revealed peak latencies of 150, 230, and 370 msec on three components not in the left anterior scalp. In another study reported in Picton and Stuss (1984), Neville (1980) recorded evoked potentials to different words bilaterally presented at the same time. An N1 peak was found to be "significantly larger over the left parietal than over the right parietal scalp." No significant asymmetry was found at other electrode sites or if the stimuli were defocussed to the point of illegibility. Samar and Berent (1986), in an evoked response study of the prelexical locus of "the syntactic priming effect", found a presumably left hemisphere temporoparietal peak at 140 msec post-stimulus for centrally presented words, which seems to reflect whether a word occurred in an appropriate or inappropriate context.

2. Hemispheric Differences in Lexical Processing

The evidence for lateralization of linguistic processing and the techniques used to obtain this evidence as outlined in the previous chapter have led most investigators to conclude that, in the majority of the population, most language functions are handled by the left cerebral hemisphere (Caplan 1987). This left hemisphere dominance has been found to be strongest in most right-handed individuals and weakest in left-handed individuals. Millar and Whitaker (1983) report on a 1967 study by Zangwill who reviewed over 2000 brain damage cases reported in the literature and found that of those with left hemisphere damage 59.7% of right-handers were aphasic, 54.9% of left-handers were aphasic, and of those with right hemisphere damage, 1.8% of right-handers were aphasic, and 29.2% of left-handers were aphasic. As Caplan (1987) reports, it appears that familial handedness may also be relevant in determining the probability of language dominance being located in one or the other or both hemispheres. He states that "detailed studies of large populations have shown that strongly right-handed individuals from right-handed families have over a 98 per cent chance of being left-hemisphere dominant for language." Caplan is quick to add, however, that even in these individuals the right hemisphere does carry out some language-related processing.

Millar and Whitaker (1983) report that right hemisphere parietal lesions have been shown to significantly disrupt the comprehension of prosody (and thus affective speech). They also report that right-hemisphere lesions result in difficulties with metaphorical language, such as "a heavy heart"; these patients frequently interpret expressions such as this as meaning physically heavy rather than sad (n.b. other explanations relating to motivational states or affect may exist for the latter effect). Caplan (1987) points out that although split-brain studies, divided visual field studies, and dichotic studies show that the right hemisphere can do some other types of language processing to a limited extent, this does not mean that it performs these kinds of processing in normal language processing.

If there is such an extensive lateralization of linguistic functions to the left hemisphere, this raises several questions. Why is there a difference between the functioning of the hemispheres (e.g. the right hemisphere is often characterized as processing holistically and the left hemisphere as processing analytically), and how is this asymmetry anatomically realized? Also, is the lateralization as complete as Caplan (1987) and others claim (i.e. all linguistic processing is normally done by the left hemisphere except for the processing of prosodic elements), or are some linguistic functions normally bilaterally represented? In relation to this last question we might ask whether a process such as lexical access might be performed by the right hemisphere as well as the left if there is some capacity for performing linguistic processes such as prosodic analysis in the right hemisphere.

One answer that has been proposed to explain, in part, why hemispheric differences appear to exist is that of Geschwind and Levitsky (1968). They observed that the previously reported anatomical asymmetry of the temporal lobe

was quite consistent within a large sample (i.e. 100 brains), and that this was a portion of the lobe that had previously been associated with linguistic processing, Wernicke's area, or, more precisely, the superior portion of the lobe in the insula known as the plana temporale. In 65% of the brains studied, the left planum temporale was larger, 11% of the brains had a larger right hemisphere planum temporale, and the rest (23%) had roughly equivalent plana temporale. Witelson (1983) reviewed a number of studies of planum temporale asymmetry and concluded that "all studies found the left planum to be larger . . . [to the extent that it is] a difference easily observable by gross visual inspection." She also points out that this asymmetry is reliable (in 70% of cases), a statement which cannot be made of other cerebral asymmetries such as those in the ventricular system, and vascular pattern asymmetries, and asymmetries "in the breadth and alignment of the frontal and posterior region of the hemispheres," asymmetries which are more difficult to relate to observed functional asymmetries.

On the cellular level, differences have also been observed between the right and left hemispheres in Broca's area (Scheibel et al. 1985). Broca's area in the left hemisphere was found to have a greater number of more extensively branched dendrites on layer III pyramidal neurons than other areas studied. They suggest that this may allow for more "degrees of freedom for the soma-dendrite complex with respect to a given input . . . [in that] each branch point represents a potential locus of enhancement or suppression of local electrical activity in the dendritic tree."

Such observations of macroscopic and microscopic asymmetries between hemispheres in language-relevant areas may be intriguing, but at this time they have not yet been definitively shown to correlate with hemispheric asymmetries in linguistic processing, although this may be an area that can be addressed on a gross scale with ERP and related technologies. For example, Garnsey (1985) used ERP to analyze the timing and localization of processes correlating with lexical access of function and content words. She found that the waveforms for these word types diverged after 200 msec, and that the difference was strongest near Broca's area, a finding consistent with function word localization evidence from aphasics. If function/content word distinctions can be identified using ERP data, can other evidence of linguistic asymmetries be demonstrated with this technology (e.g. high vs. low word imagability, inflectional vs. no inflectional morphology)? If linguistic functions that are known to be distinct are localized in one hemisphere, is it possible to demonstrate distinct anatomical localization of these processes using ERP mapping technology?

The present study attempts to answer, in part, these questions in relation to theoretically interesting neurolinguistic questions: 1) Can both hemispheres process morphologically complex words? 2) Is there an observably distinct localization of morphological processing within the cerebral hemispheres? That is, can differences between lexical access of monomorphemic and bimorphemic words be identified? 3) Can differences such as the distinction between inflectional and derivational morphological processes (Miceli and Caramazza 1988) be observed? A divided visual field study using a vocal reaction time measure by Goodall (1984) apparently

demonstrates that the left hemisphere has a superior capacity for processing morphologically complex (agentive and plural) nouns, a finding which supported the earlier finding of Gazzaniga with split-brain subjects. Also, Todorovic (1988) conducted two divided visual field experiments with morphologically complex words which demonstrated that the right hemisphere is less sensitive to case-marking. He suggests that this may result from the right hemisphere having a different type of lexicon, or it may lack the necessary processing capabilities to handle morphology and syntax. These findings along with the ERP data of Garnsey and the researchers mentioned in section 1 give the impression that the objectives of this study may be within reach with this relatively modest technology.

To aid in isolating the linguistic capacities of the cerebral hemispheres, the present experiment utilizes a divided visual field presentation of the stimuli, and in order to identify the location of morphological processing in the brain, Brain Electrical Activity Mapping (BEAM) of ERP data is utilized. To determine the potential validity of the conclusion that the ERP data is actually measuring linguistic processing and not simply noise, accuracy of the responses are also recorded. It is expected that the right hemisphere will show a lower accuracy and less variation from the baseline electrical potential than the left hemisphere for those conditions with suffixes (i.e. where morphological processing is required). Increased left hemisphere activity is expected in or near the P3 and F3 electrode sites, with the P3 activity corresponding perhaps to Wernicke's area processing of content morphemes and F3 activity corresponding to function morpheme processing (i.e. the suffixes in this case).

3. Methods

3.1. Subjects

Nine right-handed subjects (8 female, 1 male) with 20/20 (or near) vision and right eye dominance were used. Subjects were screened for history of neurological, psychiatric, and visual disorders (none reported), as well as for familial sinistrality (FS+/FS-). Data from one FS+ subject (DB) were included in the results. Subjects were native speakers of English and were between 18 and 29 years old. Subjects were paid $10 and, in some cases, also received course credit for their participation.

Three subjects (2 female, 1 male) were unable to perform the task due to an inability to read the words (as determined by the continued naming accuracy below 10%) and/or the high level of artifact leading to nearly all trials being rejected; thus their data were not included in the results.

3.2. Equipment

Stimuli were presented on an Amdek 310A amber monitor by an IBM AT. ERPs were collected and analyzed using a Bio-Logic Brain Atlas system in the Neuroimaging Laboratory of the Department of Psychiatry, Ohio State University. Brain Atlas amplifiers were calibrated for a DC offset of < 0.2 μV.

Electrode placement was performed according to the 10-20 system as described by Harner and Sannit (1974). Twenty-two gold-plated scalp electrodes were used with impedances < 10 kΩ (generally < 5 kΩ) and within 3 kΩ of each other. A "rostral" nose electrode was used as a reference electrode, and the Fpz electrode served as the ground electrode. The nose electrode was used to avoid lateralized cerebral and heart artifacts that can be a problem for ear lobe, Cz, and linked mastoid reference sites. Gain was set at 30 k and filters at 30 and 0.1 Hz. The ERP analysis window was set for 1024 msec (the first 100 msec for pre-stimulus baseline). The automatic artifact reject was used to eliminate the noisiest samples. The computer sent a trigger pulse 100 msec before stimulus presentation to the Bio-Logic Brain Atlas to initiate ERP recording.

3.3. Stimuli and Procedure

Stimuli were single words presented horizontally in upper case letters for 150 msec. Since lateral word presentations make saccades to the stimuli difficult to resist, presentation times were kept short so that the end of the stimulus presentation would likely precede the completion of the saccade. Stimuli appeared randomly five character spaces to the left or right of a central distractor (a '+') which remained on the screen throughout most of the task. The fixation symbol disappeared 1.5 sec after stimulus onset as a signal for the subject to say the word aloud. The interstimulus interval was 3 seconds. The section of each visual field where words were presented was, in terms of visual angle, between 2° (inner boundary) and 6° (outer boundary of the longest word) from the center of the screen. Words were presented with the innermost edge 2° from the center. Thus words were presented beyond the regions of highest acuity and on the edges or outside of the retinal areas with bilateral projections.

Words in 10 conditions (five linguistic variables x two visual fields) were used: 1) 16 monosyllabic nouns and verbs, 2) the same nouns and verbs with inflectional suffixes (i.e. the regular plural ending **-s**, and the third person singular present tense ending **-s**), 3) the same nouns and verbs with derivational suffixes **-less** and **-able** (these suffixes derive adjectives from the base nouns and verbs), 4) long, low frequency adjectives matched for log word frequency and word length (both letters and syllables) with the derived adjectives of condition three, and 5) short, high frequency adjectives matched for log frequency and word length (letters and syllables) with the words in conditions one and two. Word length varied from three letters (one syllable) to ten letters (two or three syllables). The words in each condition are shown in Table I along with the log frequency of each as derived

from the word frequency list of Francis and Kucera (1982). Some low frequency words used either did not occur in this list or occurred only once in over a million words.

Subjects were seated in a comfortable chair 350mm from the screen. Eye distance was maintained by having the subjects rest their foreheads against a cushioned headrest board attached to the top of the monitor. Subjects were cautioned not to lean too heavily upon the headrest to avoid producing additional

Simple Nouns & Verbs		**Inflected Nouns & Verbs**		**Derived Adjectives**	
MEAT	1.65	MEATS	1.08	MEATLESS	0
MOOD	1.57	MOODS	0.90	MOODLESS	0
TREE	1.76	TREES	2.00	TREELESS	0
LAW	2.48	LAWS	1.94	LAWLESS	0
DOOR	2.49	DOORS	1.56	DOORLESS	0
FRIEND	2.11	FRIENDS	2.21	FRIENDLESS	0
SONG	1.83	SONGS	1.77	SONGLESS	0
LEG	1.76	LEGS	1.83	LEGLESS	0
WEAR	1.51	WEARS	0.78	WEARABLE	0
BRING	2.20	BRINGS	1.60	BRINGABLE	0
GROW	1.80	GROWS	1.34	GROWABLE	0
SPEND	1.72	SPENDS	0.90	SPENDABLE	0
LEARN	1.92	LEARNS	1.00	LEARNABLE	0
KEEP	2.42	KEEPS	1.28	KEEPABLE	0
ASK	2.11	ASKS	1.26	ASKABLE	0
SERVE	2.03	SERVES	1.57	SERVABLE	0
mean log frequency	1.96		1.44		0

Short, High Frequency Adjectives		**Long, Low Frequency Adjectives**	
FRESH	1.91	INTREPID	0
RICH	1.85	VALIANT	0
VAST	1.79	SHODDY	0
SOFT	1.78	FLAXEN	0
WILD	1.73	PENSIVE	0
GREEN	1.93	BENIGN	0
THIN	1.95	JUBILANT	0.30
MERE	1.67	PRISTINE	0.30
mean log frequency	1.83		0.06

Table I: The materials for the five linguistic conditions with log word frequency.

neck muscle artifact in the signal. Subjects were instructed to remain as still as possible to avoid producing muscle artifacts, and they were instructed to avoid looking at the words. Subjects were regularly asked if they needed a break to drink some water, stretch, etc. to avoid the possibility of fatigue introducing undesirable variation in the data. This was particularly important, as the experimental session often took over five hours (including time for electrode application and removal). The first block of words presented to the subject served as a practice block, unless the subject excelled from the outset, in which case, it was included in the actual data.

The task was to name the word during the interval after its disappearance and before the next word appeared. A naming task was chosen in the hopes of avoiding the potentially longer semantic processing that may be involved in a lexical decision task, and because it has been suggested that the naming task only involves lexical access without extensive processing or influences of such variables as imageability (McMullen and Bryden 1987).

3.4. Data Analysis

The Bio-Logic Brain Atlas automatically averages EEG samples as they are recorded. This results in some noise being introduced into the averaged data, as waveforms for misreported words are averaged in also. However, a large sample size for each subject may partially compensate for this noise (provided that the across subjects error rate is not too high). Averaging across subjects, too, should help correct this problem. Averaging is used to eliminate muscle artifact noise and other non-task-relevant noise from the signal. It is assumed that the processing remains time-locked to the stimulus presentation across the presentation period (Picton and Stuss 1983; Regan 1989).

For each subject, all stimulus blocks of each condition were averaged together using the Bio-Logic Bank Mathematics Package of the Brain Atlas. No facility was available for recording trials individually. There were 32 words presented per block and up to 16 samples were collected. Two linguistic conditions were presented per block to each visual field, giving four experimental conditions per block overall. Data were collected from only two conditions per block because the Bio-Logic unit used has sufficient memory to average only two conditions at once. The results of these averages were then transformed using the Brain Atlas version of the Hjorth source derivation technique for topographic electrode data described by Hjorth (1980). This technique "preserves all information available from the International 10-20 system, in spite of the simplified presentation of local activity in the scalp field" (Hjorth 1980). Source derivation involves the subtraction of "overlap" from surrounding electrodes in the signal recorded from one electrode. This was done for each subject, when the performance of individuals was of concern, as well as for the six subject total.

Waveforms were then compared between conditions for each subject and across subjects. Comparisons included latency and amplitude measures, as are traditionally made for small arrays. The waveforms of greatest interest in this study were those considered least likely to contain muscle artifact, namely: F3, F4, C3, C4, P3, P4, Fz, Cz, and Pz. In addition to the multichannel waveform data, evoked potential maps of interpolated inter-electrode data were also used to better display spatial distribution and dynamics. These analyses were both performed after the Hjorth source derivation transformation was applied to reveal a more accurate image of the localization of the potential sources.

4. Results and Discussion

4.1. Accuracy Data

The accuracy results reported here are for five subjects.[1] The data described are for the words included in the waveform results. The accuracy data from the filler conditions of each block are not included because the possibility that eye movements could have occurred is more difficult to exclude, as the automatic artifact rejection did not affect these items. When an item in the experimental set was rejected due to artifact, the item was recorded as an error regardless of whether the word was reported correctly or not. Also, words that were reported without the suffix (if they were in the morphologically complex conditions) were not counted as correct responses even if the root (noun or verb) morpheme was reported correctly. This did occur for some subjects several times during the experimental session, particularly when the subject began to tire; however, the data on the frequency of this error have not yet been analyzed.

It might also be noted that some subjects reported words in the same syntactic category as that of the experimental items, but these were also counted as errors due to the fact that they were not identical with the stimuli presented. This type of error may be a result of the subject recognizing that many of the words in a block of stimuli belong to a particular syntactic category and guessing a word that belongs to that category, or that the subject has extracted some syntactic information from stimuli but not a sufficient amount of orthographic/phonological information to make a correct response. Further study is needed to select between these alternatives.

Figure 1 reveals a considerable difference in response accuracy across the two visual fields. Overall, the left visual field percent response accuracy is 14%

[1] A data file for one further subject (TB) recording the actual words presented to this subject was lost, making it impossible to assess the accuracy of the subject's responses. It was the experimenter's impression (based on the written record of subject's responses) that the responses given were highly accurate throughout the experimental session (i.e., across conditions).

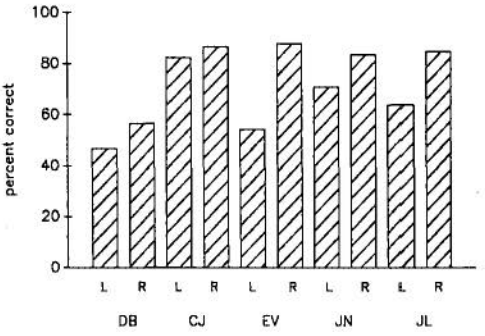

Fig. 1: Accuracy by Visual Field for each subject.

less than that of the right visual field. The direction of this difference is consistent with that reported by other investigators in previous divided visual field studies (Todorovic 1988; Beaumont 1982). Note also that the direction of the difference in visual field accuracy is the same for all subjects (LVF < RVF), although it varies greatly in magnitude -- from 4% (CJ) to 33.7% (EV). This suggests that this effect is reliable.

Subjects reported greater ease in reading words presented to the right visual field and some reported greater ease in reading the initial letter of the words. This may be due to a task-specific strategy adopted by some, if not all, of the subjects, namely: subjects appeared to attend to whatever cues they could to identify the word with the least effort and the highest accuracy. Once subjects noticed that the initial letters could be used to identify a unique word in a block of stimuli[2], they used this information (perhaps along with word shape/length information) to guess the word they had just seen. Unfortunately, the additional delay provided by the wait for the naming cue may have allowed time for a scan of memory for an appropriate match with the fragmentary data extracted from the flashed word. If words were presented several times to the same visual field (and this did happen due to the random presentation), additional information about a word could have been obtained by the occasional saccade to the word site in preparation for the appearance of the next word, if a word did then appear at the expected site. The artifact reject did sometimes reject waveforms that followed multiple presentations to the same visual field.[3]

Evidence of guessing may also be seen in the frequent occurrence (at least for some subjects) of mistakes such as reporting "mood" for "door" (both having "oo" medially), "learn" for "wear" (both having "ea" medially), "meat" for "mood" (both with an initial "m"), "leg" for "law" (both with an initial "l"), etc. Some

[2] Note that the same 16 monosyllabic nouns and verbs formed the basis for three experimental conditions. There was thus considerable repeated use of each stem.

[3] It is perhaps also worth mentioning that Tomlinson-Keasey et al. (1983) found that the initial letter of a word "does not play a critical role in word recognition" in tachistoscopic lateralized presentations.

subjects also reported that the words seemed to be displayed for a much shorter duration when a new condition was used; this was especially true for low frequency adjectives and long words.

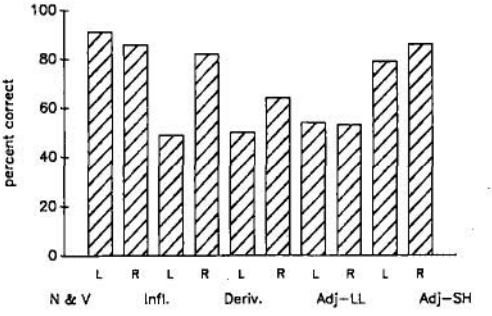

Fig. 2: Accuracy by Visual Field and Experimental Condition averaged across all subjects.

Accuracy results for the two visual fields for each experimental condition are displayed in Figure 2. In the simple nouns and verbs condition, there was little difference (5%) between visual fields, and what difference there was favored the LVF. This is perhaps small enough to be noise; indeed, as we will see, not all subjects show this LVF advantage. The inflected nouns and verbs condition shows the largest visual field difference (33%), with the LVF much lower, and the RVF at nearly the same level of accuracy as seen in the simple nouns and verbs condition. The derived adjectives (formed from the simple nouns and verbs) likewise show lower accuracy in the LVF, but with the performance for the RVF below the level for the inflected forms and monomorphemic forms.

This pattern for the suffixed words (i.e. the RVF superiority and LVF at lower accuracy is not surprising if the left hemisphere is handicapped by either a lack of function morphemes in its lexicon, or a lack of the rules for processing suffixes. An acuity gradient is not likely to be a reasonable explanation for these results, as the LVF suffixes are closer to the higher acuity regions of the visual field than those in the RVF, unless the subjects used a combination of length cues and distinctive letters (i.e. initial letters or medial "oo," etc.); the latter explanation seems unlikely, however. Long, low frequency adjectives occur at low accuracy

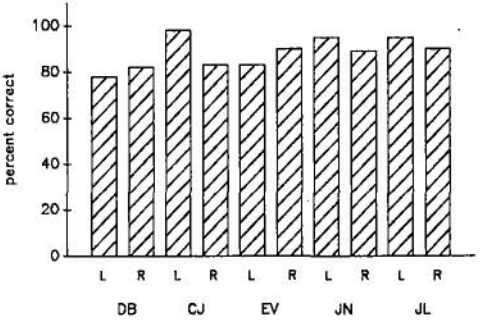

Fig. 3: Accuracy by Visual Field in the Nouns and Verbs condition for each subject.

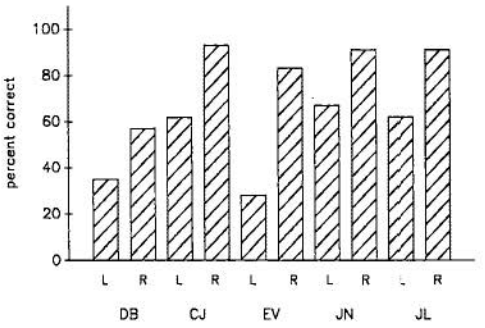

Fig. 4: Accuracy by Visual Field in the Inflected Nouns and Verbs condition for each subject.

levels regardless of visual field of presentation. This is again not surprising. However, the short, high frequency adjectives again show little difference across visual fields, with the RVF only 7% better than the LVF. These results are similar to those for the other monomorphemic, short, high frequency content words (i.e. the simple nouns and verbs condition); indeed, for the RVF the accuracy is identical for these conditions.

Data for the Nouns and Verbs condition for individual subjects are displayed in Figure 3. Little variation occurs in the accuracy of response for this condition for any subject apart from, perhaps, subject CJ who was 15% better in the LVF than in the RVF.

The Inflected Nouns and Verbs condition for individuals is summarized in Figure 4. A large RVF superiority was seen for all subjects ranging from 22% (DB) to 55% (EV) more accurate in the RVF than in the LVF. A Wilcoxson-signed test showed a significant ($p<.05$) tendency of the LVF to demonstrate lower accuracy than the RVF.

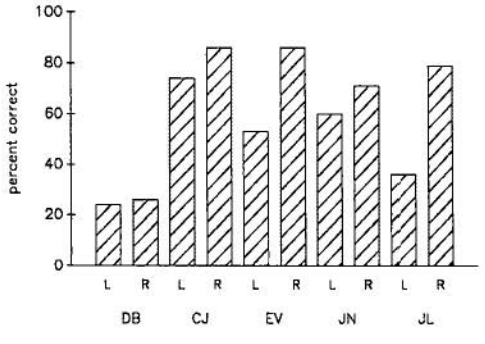

Fig. 5: Accuracy by Visual Field in the Derived Adjectives condition for each subject.

Individual results for the Derived Adjectives appear in Figure 5. Again there is a RVF superiority for all subjects, and LVF accuracy is near 50% except for CJ. The RVF accuracy is not far below that of the simple nouns and verbs condition except for DB.

The individual data for the Long, Low Frequency Adjectives condition appear in Figure 6. LVF accuracy in this condition was below 50% for all subjects except for one (CJ), and RVF accuracy was generally low as well except for EV and perhaps

CJ. This may be due to the very low frequency of these words; in effect, these were long non-words for several subjects. JN was unable to complete enough of the experiment to obtain any RVF data for this condition. It should be noted that the RVF accuracy is below that of the previous condition, derived adjectives, for some subjects. This condition was used to reveal whether adjectives derived from nouns and verbs would be processed in the same manner as the monomorphemic adjectives matched for length and word frequency. These results suggest that, at least for the left hemisphere, these adjectives are treated differently.

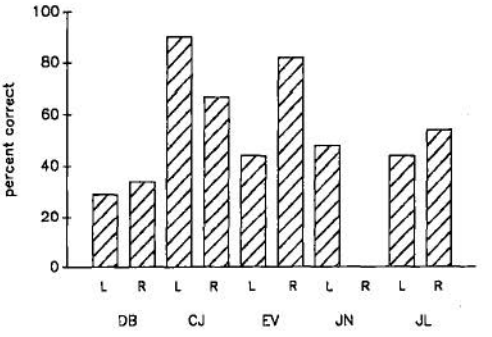

Fig. 6: Accuracy by Visual Field in the Long, Low Frequency Adjectives condition for each subject.

It may be that the difference is due to no more than the lower frequency and greater difficulty of coping with the long, low frequency adjectives. Arguably, some of the derived adjectives were also non-words for some of the subjects; nevertheless, the derived adjectives were higher frequency forms due to the higher frequency of their noun and verb base forms.

Results for the Short, High Frequency Adjectives condition for each subject are summarized by Visual Field in Figure 7. The pattern of this condition is not too different from that of the simple nouns and verbs condition as one would expect. Again, as in the last condition, JN was unable to complete the experiment, thus her data for the LVF is missing for this condition.

4.2 Waveform and Spatial Distribution Variation

Waveform data from six subjects were analyzed. Subject TB's waveform data were included although the accuracy data for this subject were lost (see discussion above). Because

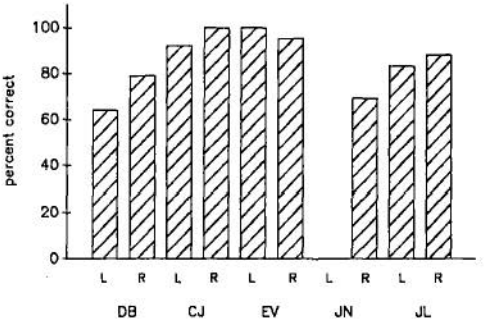

Fig. 7: Accuracy by Visual Field for the Short, High Frequency Adjectives condition for each subject.

of this small sample size and a lack of variance statistics for the waveform data reported below, caution must be exercised in interpreting these data. Because the monomorphemic adjective conditions were not crucial to the hypothesis and the data from these conditions were especially sparse, only six experimental conditions were analyzed: nouns and verbs (LVF and RVF), inflected nouns and verbs (LVF and RVF), and derived adjectives (LVF and RVF).

A sample of the waveform data is displayed in Figure 8. The cursor time was 100 msec ahead (± 976 μsec) of the actual initiation of stimulus presentation due to the ERP baseline collected before each trial. Data points were separated by 4 msec intervals, and voltages and latencies were taken from cursor locations. Waveform variation evident in this sample could be the result of variation in sample size or condition, variation in accuracy in different conditions, or any of a number of other factors.

A number of features of the waveform data seem worthy of consideration.[4] There was a P320 prominence that was clearly lateralized, with peak activity at P3 or P4 dependent upon visual field of presentation. This effect was evident across linguistic conditions. There was also a P333 peak centered at Pz which extended laterally toward P3 and P4. This peak sometimes remained more lateralized toward the hemisphere that initially processed the stimulus. Either of these effects may be a manifestation of the well-known P300 associated with visual processing.

At the Cz locus there was an N348 effect evident across all six of the analyzed conditions. This event seemed to spread over the interval from 300 to 600 msec post stimulus. Mean amplitude of the difference for this effect was -3.73 μV.

There was also an effect that appeared to be a manifestation of the phenomenon known as Contingent Negative Variation, or CNV, at F3, F4, and most especially at Fz (over the interval 400-900 msec). This may be a slow wave correlate of motor planning for the ensuing utterance of the target word. Orgogozo and Larsen (1979) report a significant increase in cerebral blood flow in the dorsomedial frontal lobe (i.e. the supplementary motor area) during vocalization. They claim that it is likely important in initiating and controlling some voluntary motor activities in man and they suggest that it may act as a higher order motor center. Regan (1989) also reports that neurons in the medial and lateral premotor cortex will become more active seconds prior to the initiation of a motor act, and in the premotor cortex changes in activity can anticipate motor activity by several minutes. He also states that the supplementary motor area appears to be crucial "in

[4] As is conventional in the ERP literature, these features will be identified by polarity and latency. Thus, P300 is a positive-going wave that diverges from some reference wave (e.g., that derived from some other experimental condition) at about 300 msec after stimulus onset. P300 at Fz is a peak that occurs at an electrode on the scalp over the frontal lobe at the zenith. Scalp site P3 is over the parietal lobe on the left side while P4 is over the corresponding site on the right side.

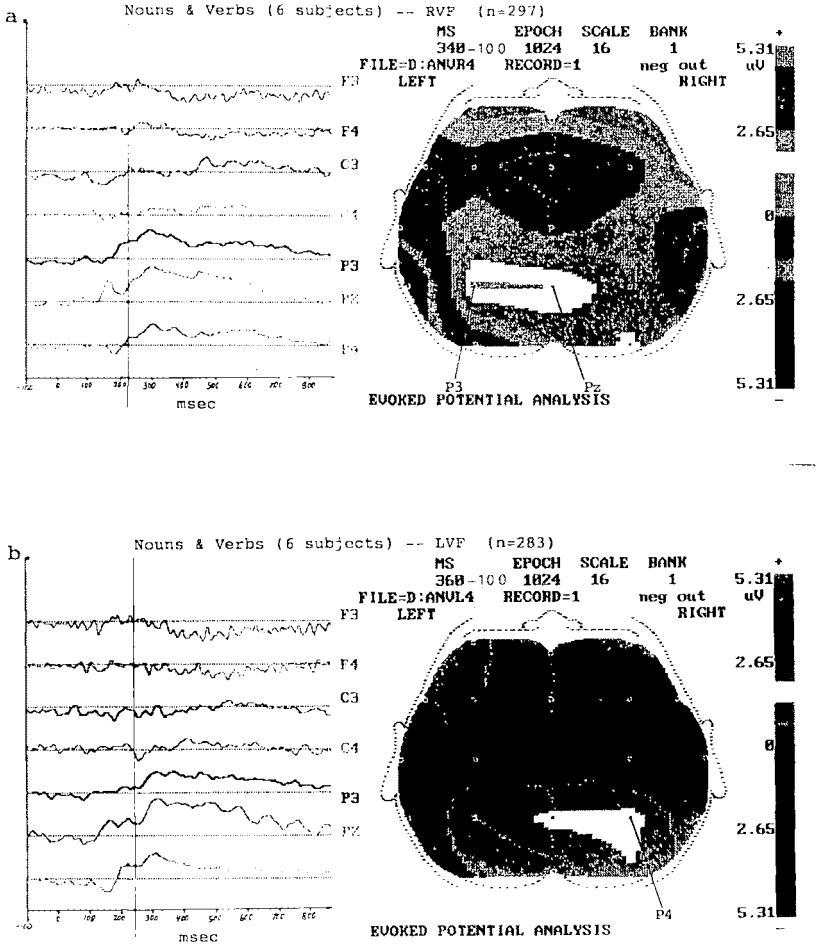

Fig. 8: Waveform data from the Nouns and Verbs condition for (a) the RVF (n=297) and (b) the LVF (n=283), for six subjects.

preparatory processes leading to initiation or suppression of movement in response to sensory input."

The latencies of certain peaks over parietal sites is of some interest. With RVF presentation, P3 mean latencies precede P4 latencies by 28 msec (n=773). LVF presentation, however, results in P4 mean peak latencies preceding P3 mean latencies by a mere 8 msec. (n=734). It is perhaps worth noting that at all electrode sites for RVF presentations the morphologically complex forms have longer latencies (especially for Pz and P4). Yet for LVF presentations, P3 and P4 have nearly identical peak latencies (except for the inflected forms). The greater delay for P4 and Pz peaks for RVF presentation may be a reflection of the initial processing by the hemisphere receiving the stimulus. The disproportionate delay at these electrode sites for the morphologically complex stimuli may be an indication of the increased difficulty of processing linguistically complex stimuli in the right hemisphere.

Analysis of peak amplitudes at the parietal sites can help assess some of the effects reported above. With RVF presentation, P3 mean peak amplitudes exceed P4 mean peak amplitudes by 1.12 μV (and Pz exceeds P3 by 0.42 μV). LVF presentation results in a P4 mean peak amplitude exceeding the P3 mean peak amplitude by 0.35 μV (and Pz exceeds P4 by 1.37 μV). The amplitude data across linguistic conditions are suggestive, but hardly unequivocal. It does appear that the visual field receiving initial stimulation has the higher peak amplitude. This is especially true of words presented to the RVF and thus processed by the left hemisphere. One might speculate that the higher amplitude of the RVF (left hemisphere) peaks results from the simultaneous activation of the greater number of neurons involved in processing linguistic stimuli in that hemisphere relative to the smaller homologous cortical areas in the right hemisphere.

5. Discussion

Though intriguing, the ERP data from this study is less reliable than the accuracy data, which seem best able to support firm judgments concerning hemispheric differences in morphological processing. This is because the ERP data is compromised by low and variable accuracy in several experimental conditions, by variation in sample sizes, and by the small number of subjects.

One observation that can be made from the ERP data, however, concerns the lateralized positive peaks that appear at P3 and P4 before the positive peak at Pz. These peaks are the strongest in the data apart from the negative peak at Cz and the positive peak at Pz. Interestingly, these peaks arise late and are lateralized to the initially stimulated hemisphere until well after initial lobe processing would be expected to be complete. Note that the visual evoked potential corresponding to processing by the striate cortex occurs around 100 msec after stimulus presentation, depending on several experimental variables (Regan 1989) - which is approximately 200 msec before these peaks observed here reach maximum. What cognitive

process(es) these peaks represent cannot be ascertained from these data, but we might speculate that they represent processing in the parietal-occipital-temporal association cortex, or perhaps, in the plana temporale (the BEAM-Hjorth localization is consistent with these possibilities). Either of these possibilities would suggest linguistic processing of the stimuli. Garnsey (1985) and others both report peaks in this general area and latency in response to linguistic stimuli.

Overall, the accuracy results are consistent with the conclusion that the right hemisphere has a lexicon which can process short, high frequency monomorphemic nouns and verbs. As for its morphological capacities, however, the accuracy data suggests that the right hemisphere by itself is deficient in its processing of the same words when inflectional and derivational suffixes are attached.

The BEAM ERP results suggest that a larger sample is needed before the relevant neurolinguistic questions can be seriously addressed. The problem of low accuracy for the LVF conditions is more difficult. Differences between linguistic conditions may be obscured within ERP data by coexisting differences in accuracy, even with larger sample sizes. Thus, it may be that only techniques such as intracerebral microelectrode arrays, or perhaps some refined version of magnetoencephalography, will support definitive claims about the neurophysiology and neuroanatomy underlying the linguistic behaviors observed here.

Acknowledgments

Several individuals have been very helpful (and patient beyond measure) while I have been working on this thesis, and I would like to thank as many as my memory allows. Wayne Cowart and Michael Torello have been invaluable in keeping me on course, and they have both been sources of much needed advice and encouragement. Tracey has not only spent many hours helping me type, but also has patiently listened to my ideas and provided support throughout. My parents have provided financial support when I've run low. Phil Enny, Gail Nakamora, and Amy Flanary have provided much needed technical support and information for which I am deeply grateful. This work was also supported in part by a grant from the National Institutes of Health (1 R01 NS22606-01) to W. Cowart, and a research grant from the OSU Department of Linguistics.

References

Allison, T., C. C. Wood, and G. McCarthy. 1986. The Central Nervous System. In M. G. H. Coles, E. Donchin, and S. W. Porges (Eds.) *Psychophysiology: Systems, Processes, and Applications*. New York: The Guilford Press, 5-25.

Anderson, D. R. 1982. *Testing the Field of Vision*. St. Louis: The C. V. Mosby Co.

Beaton, A. 1985. *Left Side, Right Side: A Review of Laterality Research.* New Haven: Yale University Press.

Beaumont, J. G. 1982. Studies with Verbal Stimuli. In J. G. Beaumont (Ed.) *Divided Visual Field Studies of Cerebral Organization.* London: Academic Press, 57-86.

Borden, G. J. and K. S. Harris. 1984. *Speech Science Primer.* Baltimore: Williams & Wilkins.

Braun, D. and B. G. Breitmeyer. 1988. Relationship between Directed Visual Attention and Saccadic Reaction Times. *Experimental Brain Research* **73:** 546-552.

Caplan, D. 1987. *Neurolinguistics and Linguistic Aphasiology: An Introduction.* New York: Cambridge University Press.

Chiarello, C. 1988. More on Words, Hemifields, and Hemispheres: A Reply to Schwartz and Kirsner. *Brain and Cognition* **7:** 394-401.

Chiarello, C., J. Senehi and M. Soulier. 1986. Viewing Conditions and Hemisphere Asymmetry for the Lexical Decision. *Neuropsychologia* **24:** 521-529.

Ducati, A., E. Fava, and E. D. F. Motti. 1988. Neuronal Generators of the Visual Evoked Potentials: Intracerebral Recording in Awake Humans. *EEG and Clinical Neurophysiology* **71:** 89-99.

Durrant, J. D. and J. H. Lovrinic. 1984. *Bases of Hearing Science.* Baltimore: Williams & Wilkins.

Francis, W. N. and H. Kucera. 1982. *Frequency Analysis of English Usage: Lexicon and Grammar.* Boston: Houghton Mifflin Co.

Garnsey, S. M. 1985. Function Words and Content Words: Reaction Time and Evoked Potential Measures of Word Recognition. *Cognitive Science Technical Report.* University of Rochester **29**

Geschwind, N. and W. Levitsky. 1968. Human Brain: Left-Right Asymmetries in Temporal Speech Region. *Science* **161:** 186-187.

Goodall, G. 1984. Morphological Complexity and Cerebral Lateralization. *Neuropsychologia* **22:** 375-380.

Harner, P. F. and T. Sannit. 1974. *A Review of the International Ten-Twenty System of Electrode Placement.* Grass Instrument Co.

Hecaen, H. and M. L. Albert. 1978. *Human Neuropsychology.* New York: John Wiley & Sons.

Hjorth, B. 1980. Source Derivation Simplifies Topographical EEG Interpretation. *American Journal of EEG Technology* **20:** 121-132.

Kutas, M., C. Van Petten, and M. Besson. 1988. Event-Related Potential Asymmetries During the Reading of Sentences. *EEG and Clinical Neurophysiology* **69:** 218-233.

Leventhal, A. G., S. J. Ault and D. J. Vitek. 1988. The Nasotemporal Division in Primate Retina: The Neural Bases of Macular Sparing and Spilting. *Science* **240:** 66-67.

McKeever, W. F. 1986. Tachistoscopic Methods in Neuropsychology. In H. J. Hannay (Ed.) *Experimental/ Techniques in Human Neuropsychology.* New York: Oxford University Press, 167-211.

McMullen, P. A. and M. P. Bryden. 1987. The Effects of Word Imageability and Frequency on Hemispheric Asymmetry in Lexical Decisions. *Brain and Language* **31:** 11-25.

Miceli, G. and A. Caramazza. 1988. Dissociation of Inflectional and Derivational Morphology. *Brain and Language* **35:** 24-65.

Millar, J. M. and H. A. Whitaker. 1983. The Right Hemisphere's Contribution to Language: A Review of Evidence from Brain-Damaged Subjects. In S. J. Segalowitz (Ed.) *Language Functions and Brain Organization.* New York: Academic Press, 87-113.

Molfese, D. L. 1983. Event-Related Potentials and Language Processes. In A. W. K. Gaillard and W. Ritter (Eds.) *Tutorials in Event-Related Potential Research: Endogenous Components.* Amsterdam: North-Holland Publishing Co., 345-368.

Orgogozo, J. M. and B. Larsen. 1979. Activation of the Supplementary Motor Area During Voluntary Movement in Man Suggests It Works as a Supramotor Area. *Science* **206:** 847-850.

Picton, T. W. and D. T. Stuss. 1984. Event-Related Potentials in the Study of Speech and Language: A Critical Review. In D. Caplan, A. R. Lecours, and A. Smith (Eds.) *Biological Perspectives on Language.* Cambridge, MA: The MIT Press, 303-360.

Petersen, S. E., P. T. Fox, M. I. Posner, M. Mintun, and M. E. Raichle. 1988. Positron Emission Tomographic Studies of the Cortical Anatomy of Single-Word Processing. *Nature* **331:** 585-589.

Regan, D. 1989. *Human Brain Electrophysiology: Evoked Potentials and Evoked Magnetic Fields in Science and Medicine.* New York: Elsevier.

Samar, V. J. and G. P. Berent. 1986. The Syntactic Priming Effect: Evoked Response Evidence for a Prelexical Locus. *Brain and Language* **28:** 250-272.

Scheible, A. B., I. Fried, L. Paul, A. Forsythe, U. Tomiyasu, A. Wechsler, A. Kao, and J. Slotnik. 1985. Differentiating Characteristics of the Human Speech Cortex: A Quantitive Golgi Study. In D. F. Benson and E. Zaidel (Eds.) *The Dual Brain: Hemispheric Specialization in Humans.* New York: The Guilford Press, 65-74.

Todorovic, D. 1988. Hemispheric Differences in Case Processing. *Brain and Language* **33:** 365-389.

Tomlinson-Keasey, C., A. Brewer, and K. Huffman. 1983. The Importance of Being First: An Analysis of Tachistoscopic Presentations of Words. *Cortex* **19:** 309-325.

Witelson, S. F. 1983. Bumps on the Brain: Right-Left Anatomic Asymmetry as a Key to Functional Lateralization. In S. J. Segalowitz (Ed.) *Language Functions and Brain Organization.* New York: Academic Press, 117-144.

Young, A. W. 1982. Methodological and Theoretical Bases of Visual Hemifield Studies. In J. G. Beaumont (Ed.) *Divided Visual Field Studies of Cerebral Organization.* London: Academic Press, 11-27.

Zaidel, E. 1978. Lexical Organization in the Right Hemisphere. In P. A. Buser and A. Rougel-Buser (Eds.) *Cerebral Correlates of Conscious Experience.* Amsterdam: Elsevier/North-Holland Biomedical Press, 177-197.